Research Needs to Improve Agricultural Productivity and Food Quality, with Emphasis on Biotechnology

Jennifer A. Thomson

Department of Molecular and Cell Biology, University of Cape Town, Cape Town, Rondebosch 7001, South Africa

ABSTRACT Research into agricultural productivity, especially for crops in the developing world, should include resistance to plant viruses, fungi and the parasitic weed Striga. It must also include research into the development of resistance to Bacillus thuringiensis (Bt) toxin–expressing crops. Drought- and heat-tolerant crops, and those that can combat the problems of soil deficiencies, are required, and vaccine production in plants should be a high priority. Research into food quality should include the equivalent of “golden rice” in maize, the enhancement of the production of phytosterols and improved qualities of vegetable oils. J. Nutr. 132: 3441S–3442S, 2002.

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The Green Revolution was remarkably successful in improving yields of food crops in many parts of the world. It was less successful, however, in Sub-Saharan Africa, where yields have hardly changed in 40 y and where cereal production per capita is steadily declining (1). It has been estimated that with current yields the projected shortfall of cereals will be 88.7 million tons by 2025 (2). Unless new technology is introduced to improve productivity, the subcontinent, and other parts of the developing world in similar situations, will experience major food shortages. One such technology that could fulfill some of these requirements is biotechnology.

This reports deals with the research that needs to be undertaken to improve agricultural productivity and food quality in developing countries, especially in Sub-Saharan Africa.

Biotic stress

Africa is home to a number of endemic plant viruses, including maize streak virus and African cassava mosaic virus. Zambia recently lost an entire annual crop to the latter virus. Scientists in South Africa have produced transgenic plants, expressing mutant-truncated replication-associated protein Maize streak virus genes, that are resistant to the virus. However, field trials are being hampered by the lack of suitable facilities. An international research program based at the Donald Danforth Center in St. Louis, Missouri, is aimed at developing transgenic cassava resistant to African cassava mosaic virus (personal communication, Dr. C. Fouquet, Donald Danforth Center).

Insect-resistant cotton expressing the Bacillus thuringiensis (Bt) toxin gene has been grown successfully by small-scale farmers in South Africa for a number of years. A recent independent study of the effects of these plantings came to the following conclusions (3):

- The average yield per hectare and per kilogram was higher for adopters than for nonadopters.
- The increases in yield and the reduction in chemical costs outweighed the higher seed cost of Bt cotton.
- There were heavy rainfalls in 1999 and Bt adopters experienced less decrease in yield than nonadopters.

However, research needs to be carried out into the development of insect resistance to the Bt toxin.

Fungal infections, both preharvest and postharvest, are a major problem in many parts of the developing world. In addition to crop spoilage or destruction, fungi can produce mycotoxins, such as aflatoxin, which can cause toxic hepatitis and liver and esophageal cancer in humans (4). Bt maize could help to alleviate these problems, especially among small-scale farmers who store their harvested crop for use throughout the year. If the kernels have not been subjected to insect damage, they will be less susceptible to subsequent fungal infection. Scientists have shown that the rotting of maize cobs due to fungal infection is greatly reduced in Bt maize (5,6). In addition, Bt-protected maize contains lower levels of fumonisins, a fungal toxin that can be fatal to livestock (7). However, research into fungus-resistant crops is lagging behind some of the other biotic stress problems.

Striga is a parasitic weed that grows on weak maize, rice and sorghum plants. It can be treated with a herbicide at doses of 5 g/hectare. However, that would require the host plants to be resistant to the herbicide. Research is being carried out on this problem, but it should have a higher priority than the current status.

3 Abbreviation used: Bt, Bacillus thuringiensis.
Abiotic stress

The increase in desertification in Sub-Saharan Africa is cause for considerable concern. Transgenic crops that can tolerate some measure of drought and heat stress could alleviate some of the subcontinent's lack of productivity. "For many developing countries even slight improvements in stress tolerance would significantly increase yields" (8). Africa is home to a large number of indigenous plants with a remarkable ability to withstand heat and desiccation. These so-called "resurrection plants" are found in deserts and grow in cracks in rocks. Scientists in South Africa are using one of these plants, the monocotyledonous Xerophyta viscosa, as a source of genes to develop drought- and heat-tolerant crops (9).

In most of Africa, virgin soils vary from acid to very acid, with pH values of 3.5–4.5. Cabbage production, for instance, requires the application of about 18 tons of lime per hectare. Acidity in the soil causes aluminum and manganese to become soluble, and this leads to toxicity. On the other hand, critical minerals such as molybdenum precipitate and are therefore unavailable to plants. In addition, levels of phosphate in the soil are often low. Again, using cabbage as an example, phosphate concentrations in the soil may be in the order of two parts per million (ppm), but this crop requires levels of 60–80 ppm and maize requires 40 ppm. Sources of phosphate are limited and expensive, and organic sources such as compost are usually too low in phosphate to be useful. Research into these problems should be viewed as a high priority.

Vaccine production in plants

Although not an agricultural or a food issue, the possibility of producing vaccines in plants should be included in a discussion of agricultural biotechnology in developing countries. The approach being taken by scientists in South Africa is not to produce edible vaccines but rather to use plants such as tobacco as "phactories" for vaccine production. This can be done either by producing transgenic plants expressing the viral protein to be used as the vaccine or by cloning the gene into a systemically infecting virus, such as Tobacco mosaic virus. The vaccine protein can be extracted from the tobacco plants and formulated into pills or capsules for oral ingestion. Using this route, the vaccine need not be as pure as if it were to be injected (personal communication, Prof. E. P. Rybicki, Department of Molecular and Cellular Biology, University of Cape Town). This approach will be suitable for viruses that invade the body via mucosal membranes, including such as human immunodeficiency virus and human papilloma virus, the leading cause of vaginal cancer in African women.

Food quality

According to the World Health Organization, 250 million children worldwide are at risk from vitamin A deficiencies, and 10 million people face illness and death. Many of these will experience impaired vision, decreased immunity and protein malnutrition because vitamin A affects the absorption and use of amino acids. "Golden rice," which carries genes from the daffodil, produces beta-carotene, which can be converted by a potential of 2.4 billion people who eat rice as their staple diet into vitamin A (10). What other developing countries need these genes incorporated into maize.

Cardiovascular disease, which is linked to high levels of dietary cholesterol, is becoming ever more prevalent, in both developing and developed worlds. It is known that plant sterols (phytosterols) can reduce cholesterol in humans by 10–15% due to interference with cholesterol absorption in the gastrointestinal tract. Plant sterols are not currently available in adequate quantities in the foods we eat, and scientists are actively engaged in increasing the phytosterol content of several grains (11).

Vegetable oils are another example of how biotechnology can improve the quality of a food product. Canola and soybeans, the source of most of the cooking oil in the Western world, often contain trans-fatty acids, which may increase the risks of heart disease. Genetically modified varieties that are free of these acids are being evaluated for commercial viability. Furthermore, unsaturated fatty acids are healthier than saturated fatty acids. Concentrations of oleic acid, an unsaturated fatty acid, have been increased from 25% to 85% in the seeds of genetically modified varieties (12).

Conclusions

It is clear that a great deal of biotechnological research is being conducted into the improvement of agricultural productivity and food quality, for both developing and developed countries. However, farmers will not plant crops with such improvements unless they are linked to increased yields and increased profits. Scientists undertaking this research need to bear this in mind and ensure that the plants they produce do indeed provide improved yields and profits.

LITERATURE CITED